Underhood Thermal Management in Hybrid Electric Vehicles

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Three Steps to Understanding Underhood Thermal Management in HEVs

- Applying high-performance computing to automotive design and manufacturing
  - Cooperative Research and Development Agreement (CRADA) between the U.S. Council for Automotive Research (USCAR) and U.S. Department of Energy (DOE) laboratories
- Analyzing automotive underhood thermal management with 3-D coupled thermal-hydrodynamic computer models
  - CRADA among USCAR/ADAPCO/Argonne/ORNL
- HEV underhood thermal management pilot project
  - Argonne/ADAPCO joint project

Applying Supercomputing to Thermal Management in Vehicles

In 1993, DOE laboratories and USCAR initiated a CRADA to develop advanced engineering analysis methods/codes.

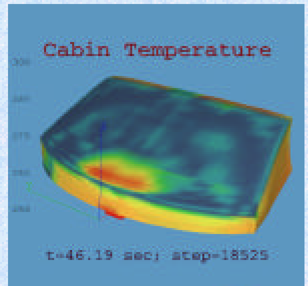
- USCAR established the Supercomputing Automotive Applications Partnership (SCAAP) to oversee the CRADA.
- The initial CRADA included an emphasis on computational fluid dynamics (CFD), focused on the CHAD code, originally developed at Los Alamos National Laboratory.
- Argonne and ORNL developed thermal-analysis models for CHAD, focused on HVAC systems.
- USCAR selected ADAPCO for possible commercialization of CHAD and/or its models and methodology.

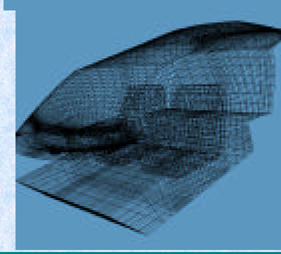
Underhood Thermal Management in HEVs

- The underhood thermal management CRADA began in 1998 to extend CHAD to new class of problems, with additional emphasis on numerical performance, with approval of USCAR and industry/government representatives from the Partnership for Next Generation Vehicles (PNGV).
- The pilot project on use of CFD for HEV underhood thermal management was initiated between Argonne and ADAPCO in August 1999.

Using High-Performance Computing in Automotive Design and Manufacturing

- CRADA with USCAR's SCAAP
- Multiyear joint effort between USCAR and DOE labs (Argonne, LANL, LLNL, ORNL, SNL)
- Technical Focus
  - Next-generation CFD code - CHAD
  - Advanced models for crash simulation codes, such as DYNA-3D
- Argonne Technical Focus
  - Thermal and hydrodynamic models in CHAD for HVAC analysis
  - Advanced models for composite materials in DYNA-3D





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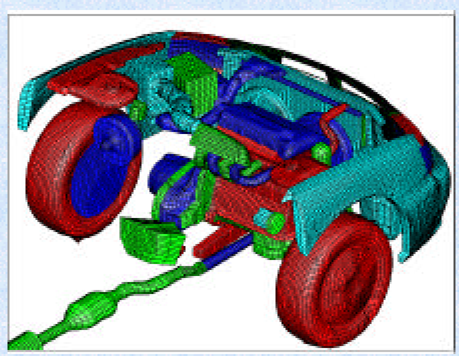
Automotive Underhood Thermal Management Analysis with 3-D Coupled Thermal-Hydrodynamic Computer Models

- CRADA with ADAPCO, General Motors, Ford, DaimlerChrysler, and ORNL
  - Fan, radiator and heat transport system models
  - Improved numerics in CHAD
  - Radiation heat transfer model
  - Verification and validation
  - Virtual reality for examination of results



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Roles of Partners

- Argonne National Laboratory
  - Develop and implement fan and heat exchanger models in CHAD
  - Develop cooling system model in CHAD
  - Develop and implement robust numerical methods for CHAD
  - Develop virtual reality techniques
- Oak Ridge National Laboratory
  - Develop and implement radiation heat transfer capability in CHAD
- ADAPCO
  - Identify test problems and develop computational mesh
  - Implement models and advanced methods in commercial version of CHAD
  - Participate verification and validation of models in CHAD
- USCAR
  - Specify test problems
  - Participate in verification and validation of models in CHAD

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HEV Pilot Project

- Model description
  - External domain
  - Front end
  - Underhood components
  - Heat exchanger package
- Preliminary results
  - Flow field
  - Temperatures
- Conclusions

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HEV Project Summary

- A pilot project for thermal analysis of an HEV was recently completed with the STAR-CD general-purpose CFD software
  - Mesh of a generic HEV
  - Focus on radiator thermal performance
- Characteristics of the model
  - 3.6 million fluid cells
  - radiator as dual-stream, single-phase heat exchanger
  - fans modeled with implicit multiple reference frames
- Solution performed on an IBM Power 3 SMP cluster
  - 8 processors, each with 512 Mb memory
  - 1400 iterations in 28 hours

Thermal Issues in HEV Operation

- Simultaneous, sustained operation of motor and engine (hill climbing, passing)
- Low-speed operation with AC load
  - AC requires engine operation
  - cooling airflow is reduced at low speed
- Battery cooling
  - relationship to battery performance
  - connection with AC loading
- Critical components
  - inverter/Converter: Provide motor and generator logic and serves accessory loads
  - computers for engine, inverter, ABS, steering, battery management, navigation and dashboard (location driven by electrical noise avoidance as well as thermal issues)

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Model Description

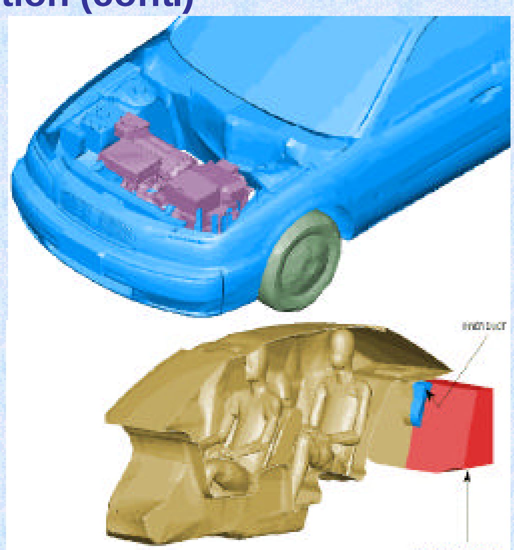
- The model consists of flow domain that approximates a wind-tunnel environment for a stationary car (ground moving)

Boundary Conditions for Vehicle Speed of 60 km/h

Air Inlet Velocity	16.67	m/s
Air Inlet Temperature	20	ºC
Ambient Pressure	1.0	atm
Wheel Speed	500	rpm
Coolant Flow Rate	1.0	kg/s
Coolant Inlet Temp.	85	ºC
Fan Speed	1350	rpm

Model Description (cont.)

- The entire vehicle (including the passenger compartment) is represented to model various interrelated airflow phenomena and thermal activity.
- Combining 3-D flow and heat transfer into one large model allows assessment of inherent interdependency of components.



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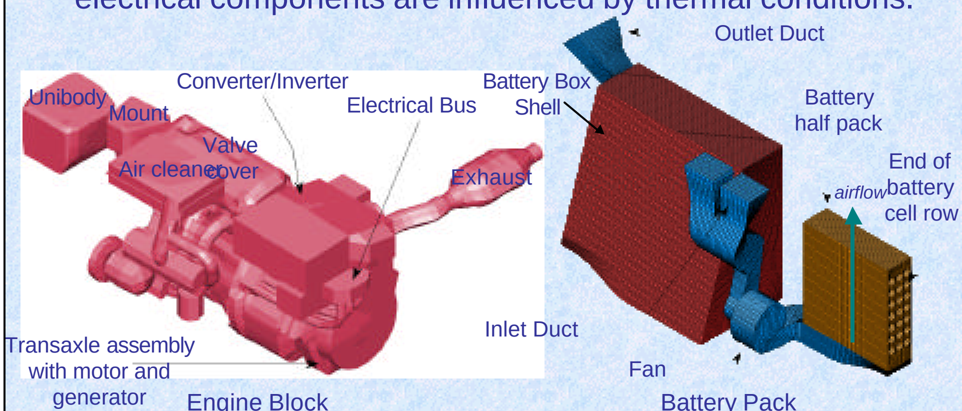
Model Description (cont.)

- Detailed geometric modeling of the front end of the vehicle is important because the openings play a critical role in the effectiveness of a powertrain cooling scheme.
  - They provide airflow to the front-end heat exchanger package (radiator and condenser).
  - This region is subject to frequent design changes.

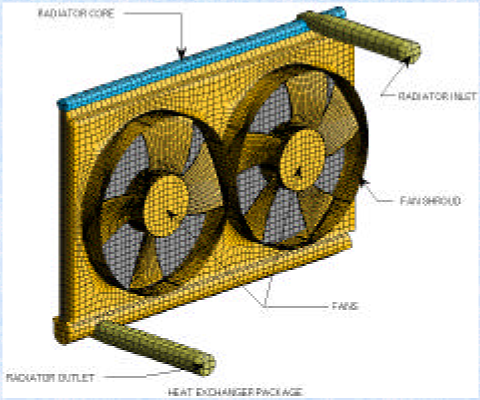
Model Description (cont.)

- The performance and reliability of the battery pack and other electrical components are influenced by thermal conditions.



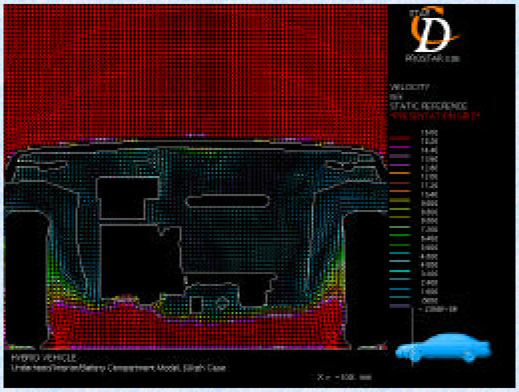
Model Description (cont.)

- The radiator is modeled as a dual-stream, single-phase heat exchanger.
- Pressure drops through the radiator core are accounted for by treating both fluid streams as porous media.
- Heat transfer between fluid streams are user specified on the basis of available test data.
- Airflow due to spin of the fan blades is simulated in a rotating frame of reference (coupling of solutions in rotating and inertial frames is implicit).



Results

- Velocity vectors in y-z plane with respect to moving vehicle
- View from back of the vehicle along x direction



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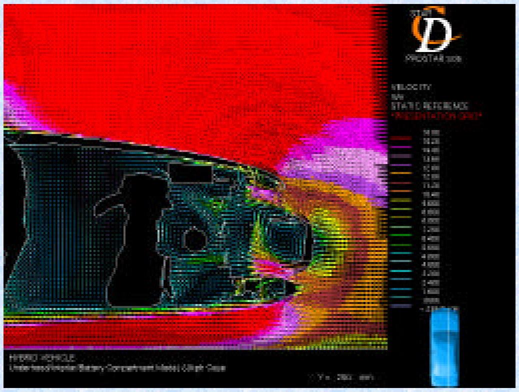
Results (cont.)

- Velocity vectors in x-z plane with respect to moving vehicle
- View from passenger side along y direction



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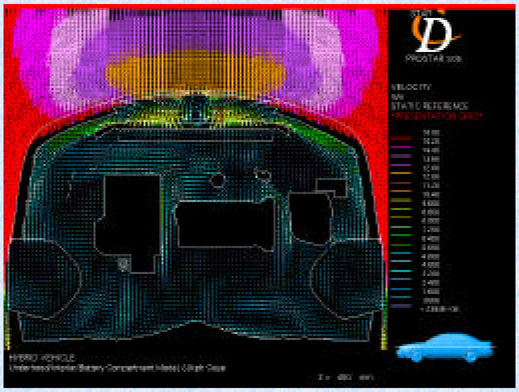
Results (cont.)

- Velocity vectors in x-y plane with respect to moving vehicle
- View from top of the vehicle along the z direction



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Results (cont.)

- Temperature contours in y-z plane
- View from back of the vehicle along x direction

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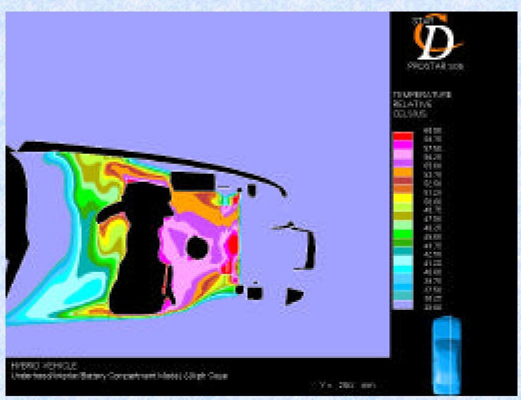
Results (cont.)

- Temperature contours in x-z plane
- View from passenger side of the vehicle along y direction



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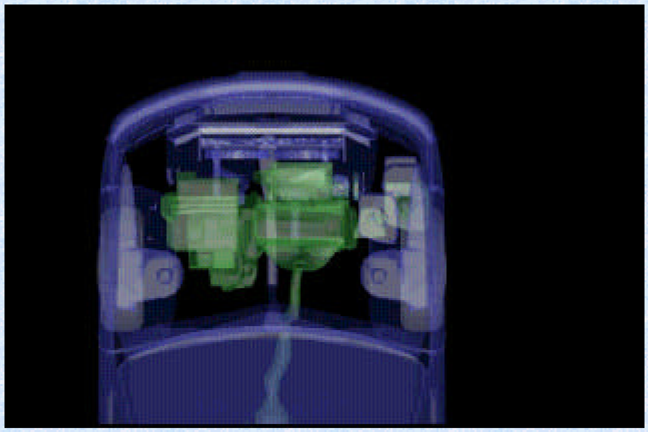
Results: Particle Tracks



Conclusions

- The pilot project for underhood thermal management of a generic HEV highlights modeling capabilities with STAR.
- The 3-D fluid flow and heat-transfer calculations for the entire vehicle provide a virtual test facility for
  - assessing the interdependence of underhood components
  - studying load conditions
  - identifying critical components
- Analytical CFD capabilities complement experimental programs in the design of next-generation advanced vehicles:
  - battery temperature optimization
  - radiator configuration
  - integrity and reliability of components (temperature limits and thermal cycling)
  - AC interaction with battery cooling and engine exhaust

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